

# A Thorough Examination of the CNN/Daily Mail Reading Comprehension Task

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## Abstract

Enabling a computer to understand a document so that it can answer comprehension questions is a central, yet unsolved goal of NLP. A key factor impeding its solution by machine learned systems is the limited availability of human-annotated data. Hermann et al. (2015) seek to solve this problem by creating over a million training examples by pairing *CNN* and *Daily Mail* news articles with their summarized bullet points, and show that a neural network can then be trained to give good performance on this task. In this paper, we conduct a thorough examination of this new reading comprehension task. Our primary aim is to understand what depth of language understanding is required to do well on this task. We approach this from one side by doing a careful hand-analysis of a small subset of the problems and from the other by showing that simple, carefully designed systems can obtain accuracies of 73.6% and 76.6% on these two datasets, exceeding current state-of-the-art results by 7–10% and approaching what we believe is the ceiling for performance on this task.<sup>1</sup>

## 1 Introduction

Reading comprehension (RC) is the ability to read text, process it, and understand its meaning.<sup>2</sup> How to endow computers with this capacity has been an elusive challenge and a long-standing goal of Artificial Intelligence (e.g., (Norvig, 1978)). Genuine reading comprehension involves interpretation of

the text and making complex inferences. Human reading comprehension is often tested by asking questions that require interpretive understanding of a passage, and the same approach has been suggested for testing computers (Burges, 2013).

In recent years, there have been several strands of work which attempt to collect human-labeled data for this task – in the form of document, question and answer triples – and to learn machine learning models directly from it (Richardson et al., 2013; Berant et al., 2014; Wang et al., 2015). However, these datasets consist of only hundreds of documents, as the labeled examples usually require considerable expertise and neat design, making the annotation process quite expensive. The subsequent scarcity of labeled examples prevents us from training powerful statistical models, such as deep learning models, and would seem to prevent a system from learning complex textual reasoning capacities.

Recently, researchers at *DeepMind* (Hermann et al., 2015) had the appealing, original idea of exploiting the fact that the abundant news articles of *CNN* and *Daily Mail* are accompanied by bullet point summaries in order to heuristically create large-scale supervised training data for the reading comprehension task. Figure 1 gives an example. Their idea is that a bullet point usually summarizes one or several aspects of the article. If the computer understands the content of the article, it should be able to infer the missing entity in the bullet point.

This is a clever way of creating supervised data cheaply and holds promise for making progress on training RC models; however, it is unclear what level of reading comprehension is actually needed to solve this somewhat artificial task and, indeed, what statistical models that do reasonably well on this task have actually learned.

In this paper, our aim is to provide an in-depth and thoughtful analysis of this dataset and what

<sup>1</sup>Our code is available at <https://github.com/danqi/rc-cnn-dailymail>.

<sup>2</sup>[https://en.wikipedia.org/wiki/Reading\\_comprehension](https://en.wikipedia.org/wiki/Reading_comprehension)

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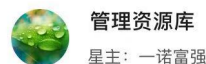
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## Passage

( @entity4 ) if you feel a ripple in the force today , it may be the news that the official @entity6 is getting its first gay character . according to the sci-fi website @entity9 , the upcoming novel " @entity11 " will feature a capable but flawed @entity13 official named @entity14 who " also happens to be a lesbian . " the character is the first gay figure in the official @entity6 -- the movies , television shows , comics and books approved by @entity6 franchise owner @entity22 -- according to @entity24 , editor of " @entity6 " books at @entity28 imprint @entity26 .

Question	Answer
characters in " @placeholder " movies have gradually become more diverse	@entity6

Figure 1: An example item from dataset *CNN*.

level of natural language understanding is needed to do well on it. We demonstrate that simple, carefully designed systems can obtain high, state-of-the-art accuracies of 73.6% and 76.6% on *CNN* and *Daily Mail* respectively. We do a careful hand-analysis of a small subset of the problems to provide data on their difficulty and what kinds of language understanding are needed to be successful and we try to diagnose what is learned by the systems that we have built. We conclude that: (i) this dataset is easier than previously realized, (ii) straightforward, conventional NLP systems can do much better on it than previously suggested, (iii) the distributed representations of deep learning systems are very effective at recognizing paraphrases, (iv) partly because of the nature of the questions, current systems much more have the nature of single-sentence relation extraction systems than larger-discourse-context text understanding systems, (v) the systems that we present here are close to the ceiling of performance for single-sentence and unambiguous cases of this dataset, and (vi) the prospects for getting the final 20% of questions correct appear poor, since most of them involve issues in the data preparation which undermine the chances of answering the question (coreference errors or anonymization of entities making understanding too difficult).

## 2 The Reading Comprehension Task

The RC datasets introduced in (Hermann et al., 2015) are made from articles on the news websites *CNN* and *Daily Mail*, utilizing articles and their bullet point summaries.<sup>3</sup> Figure 1 demonstrates

<sup>3</sup>The datasets are available at <https://github.com/deepmind/rc-data>.

an example<sup>4</sup>: it consists of a passage  $p$ , a question  $q$  and an answer  $a$ , where the passage is a news article, the question is a cloze-style task, in which one of the article’s bullet points has had one entity replaced by a placeholder, and the answer is this questioned entity. The goal is to infer the missing entity (answer  $a$ ) from all the possible entities which appear in the passage. A news article is usually associated with a few (e.g., 3–5) bullet points and each of them highlights one aspect of its content.

The text has been run through a Google NLP pipeline. It is tokenized, lowercased, and named entity recognition and coreference resolution have been run. For each coreference chain containing at least one named entity, all items in the chain are replaced by an @entity $n$  marker, for a distinct index  $n$ . Hermann et al. (2015) argue convincingly that such a strategy is necessary to ensure that systems approach this task by understanding the passage in front of them, rather than by using world knowledge or a language model to answer questions without needing to understand the passage. However, this also gives the task a somewhat artificial character. On the one hand, systems are greatly helped by entity recognition and coreference having already been performed; on the other, they suffer when either of these modules fail, as they do (in Figure 1, “the character” should probably be coreferent with @entity14; clearer examples of failure appear later on in our data analysis). Moreover, this inability to use world knowledge also makes it much more difficult for a human to do this task – occasionally it is very difficult or impossible for a human to determine the correct answer when presented with an item anonymized in this way.

The creation of the datasets benefits from the sheer volume of news articles available online, so they offer a large and realistic testing ground for statistical models. Table 1 provides some statistics on the two datasets: there are 380k and 879k training examples for *CNN* and *Daily Mail* respectively. The passages are around 30 sentences and 800 tokens on average, while each question contains around 12–14 tokens.

In the following sections, we seek to more deeply understand the nature of this dataset. We first build some straightforward systems in order to get a better idea of a lower-bound for the performance of

<sup>4</sup>The original article can be found at <http://www.cnn.com/2015/03/10/entertainment/feat-star-wars-gay-character/>.

	CNN	Daily Mail
# Train	380,298	879,450
# Dev	3,924	64,835
# Test	3,198	53,182
Passage: avg. tokens	761.8	813.1
Passage: avg. sentences	32.3	28.9
Question: avg. tokens	12.5	14.3
Avg. # entities	26.2	26.2

Table 1: Data statistics of the *CNN* and *Daily Mail* datasets. The avg. tokens and sentences in the passage, the avg. tokens in the query, and the number of entities are based on statistics from the training set, but they are similar on the development and test sets.

current NLP systems. Then we turn to data analysis of a sample of the items to examine their nature and an upper bound on performance.

### 3 Our Systems

In this section, we describe two systems we implemented – a conventional entity-centric classifier and an end-to-end neural network. While Hermann et al. (2015) do provide several baselines for performance on the RC task, we suspect that their baselines are not that strong. They attempt to use a frame-semantic parser, and we feel that the poor coverage of that parser undermines the results, and is not representative of what a straightforward NLP system – based on standard approaches to factoid question answering and relation extraction developed over the last 15 years – can achieve. Indeed, their frame-semantic model is markedly inferior to another baseline they provide, a heuristic word distance model. At present just two papers are available presenting results on this RC task, both presenting neural network approaches: (Hermann et al., 2015) and (Hill et al., 2016). While the latter is wrapped in the language of end-to-end memory networks, it actually presents a fairly simple window-based neural network classifier running on the CNN data. Its success again raises questions about the true nature and complexity of the RC task provided by this dataset, which we seek to clarify by building a simple attention-based neural net classifier.

Given the (passage, question, answer) triple  $(p, q, a)$ ,  $p = \{p_1, \dots, p_m\}$  and  $q = \{q_1, \dots, q_l\}$  are sequences of tokens for the passage and

question sentence, with  $q$  containing exactly one “@placeholder” token. The goal is to infer the correct entity  $a \in p \cap E$  that the placeholder corresponds to, where  $E$  is the set of all abstract entity markers. Note that the correct answer entity must appear in the passage  $p$ .

#### 3.1 Entity-Centric Classifier

We first build a conventional feature-based classifier, aiming to explore what features are effective for this task. This is similar in spirit to (Wang et al., 2015), which at present has very competitive performance on the MCTest RC dataset (Richardson et al., 2013). The setup of this system is to design a feature vector  $f_{p,q}(e)$  for each candidate entity  $e$ , and to learn a weight vector  $\theta$  such that the correct answer  $a$  is expected to rank higher than all other candidate entities:

$$\theta^\top f_{p,q}(a) > \theta^\top f_{p,q}(e), \forall e \in E \cap p \setminus \{a\} \quad (1)$$

We employ the following feature templates:

1. Whether entity  $e$  occurs in the passage.
2. Whether entity  $e$  occurs in the question.
3. The frequency of entity  $e$  in the passage.
4. The first position of occurrence of entity  $e$  in the passage.
5.  $n$ -gram exact match: whether there is an exact match between the text surrounding the placeholder and the text surrounding entity  $e$ . We have features for all combinations of matching left and/or right one or two words.
6. Word distance: we align the placeholder with each occurrence of entity  $e$ , and compute the average minimum distance of each non-stop question word from the entity in the passage.
7. Sentence co-occurrence: whether entity  $e$  co-occurs with another entity or verb that appears in the question, in some sentence of the passage.
8. Dependency parse match: we dependency parse both the question and all the sentences in the passage, and extract an indicator feature of whether  $w \xrightarrow{r} \text{@placeholder}$  and  $w \xrightarrow{r} e$  are both found; similar features are constructed for  $\text{@placeholder} \xrightarrow{r} w$  and  $e \xrightarrow{r} w$ .

#### 3.2 End-to-end Neural Network

Our neural network system is based on the *AttentiveReader* model proposed by (Hermann et al., 2015). The framework can be described in the following three steps (see Figure 2):

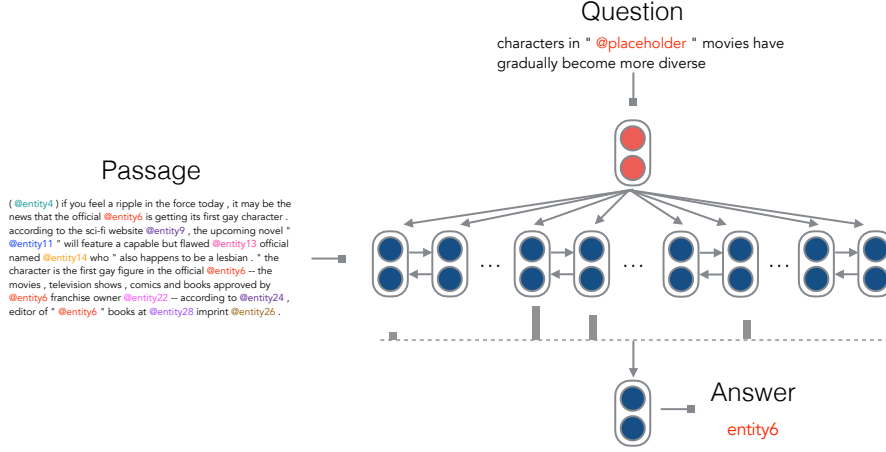


Figure 2: Our neural network architecture for the reading comprehension task.

**Encoding:** First, all the words are mapped to  $d$ -dimensional vectors via an embedding matrix  $E \in \mathbb{R}^{d \times |\mathcal{V}|}$ ; therefore we have  $p: \mathbf{p}_1, \dots, \mathbf{p}_m \in \mathbb{R}^d$  and  $q: \mathbf{q}_1, \dots, \mathbf{q}_l \in \mathbb{R}^d$ .

Next we use a shallow bi-directional recurrent neural network (RNN) with hidden size  $\tilde{h}$  to encode contextual embeddings  $\tilde{\mathbf{p}}_i$  of each word in the passage,

$$\begin{aligned} \vec{\mathbf{h}}_i &= \text{RNN}(\vec{\mathbf{h}}_{i-1}, \mathbf{p}_i), i = 1, \dots, m \\ \leftarrow \mathbf{h}_i &= \text{RNN}(\leftarrow \mathbf{h}_{i+1}, \mathbf{p}_i), i = m, \dots, 1 \end{aligned}$$

and  $\tilde{\mathbf{p}}_i = \text{concat}(\vec{\mathbf{h}}_i, \leftarrow \mathbf{h}_i) \in \mathbb{R}^h$ , where  $h = 2\tilde{h}$ . Meanwhile, we use another bi-directional RNN to map the question  $\mathbf{q}_1, \dots, \mathbf{q}_l$  to an embedding  $\mathbf{q} \in \mathbb{R}^h$ . We choose to use Gated Recurrent Unit (GRU) (Cho et al., 2014) in our experiments because it performs similarly but is computationally cheaper than LSTM.

**Attention:** In this step, the goal is to compare the question embedding and all the contextual embeddings, and *select* the pieces of information that are relevant to the question. We compute a probability distribution  $\alpha$  depending on the degree of relevance between word  $p_i$  (in its context) and the question  $q$  and then produce an output vector  $\mathbf{o}$  which is a weighted combination of all contextual embeddings  $\{\tilde{\mathbf{p}}_i\}$ :

$$\alpha_i = \text{softmax}_i \mathbf{q}^T \mathbf{W}_s \tilde{\mathbf{p}}_i \quad (2)$$

$$\mathbf{o} = \sum_i \alpha_i \tilde{\mathbf{p}}_i \quad (3)$$

$\mathbf{W}_s \in \mathbb{R}^{h \times h}$  is used in a bilinear term, which allows us to compute a similarity between  $\mathbf{q}$  and  $\tilde{\mathbf{p}}_i$  more flexibly than with just a dot product.

**Prediction:** Using the *output* vector  $\mathbf{o}$ , the system outputs the most likely answer using:

$$a = \arg \max_{a \in p \cap E} W_a^T \mathbf{o} \quad (4)$$

Finally, the system adds a softmax function on top of  $W_a^T \mathbf{o}$  and adopts a negative log-likelihood objective for training.

**Differences from (Hermann et al., 2015).** Our model basically follows the *AttentiveReader*. However, to our surprise, our experiments observed nearly **7–10%** improvement over the original *AttentiveReader* results on *CNN* and *Daily Mail* datasets (discussed in Sec. 4). Concretely, our model has the following differences:

- We use a bilinear term, instead of a tanh layer to compute the relevance (attention) between question and contextual embeddings. The effectiveness of the simple bilinear attention function has been shown previously for neural machine translation by (Luong et al., 2015).
- After obtaining the weighted contextual embeddings  $\mathbf{o}$ , we use  $\mathbf{o}$  for direct prediction. In contrast, the original model in (Hermann et al., 2015) combined  $\mathbf{o}$  and the question embedding  $\mathbf{q}$  via another non-linear layer before making final predictions. We found that we could remove this layer without harming performance. We believe it is sufficient for the model to learn to return the entity to which it maximally gives attention.
- The original model considers all the words from the vocabulary  $\mathcal{V}$  in making predictions. We think this is unnecessary, and only predict among entities which appear in the passage.

Of these changes, only the first seems important; the other two just aim at keeping the model simple.

**Window-based MemN2Ns (Hill et al., 2016).** Another recent neural network approach proposed by (Hill et al., 2016) is based on a memory network architecture (Weston et al., 2015). We think it is highly similar in spirit. The biggest difference is their way of encoding passages: they demonstrate that it is most effective to only use a 5-word context window when evaluating a candidate entity and they use a positional unigram approach to encode the contextual embeddings: if a window consists of 5 words  $x_1, \dots, x_5$ , then it is encoded as  $\sum_{i=1}^5 E_i(x_i)$ , resulting in 5 separate embedding matrices to learn. They encode the 5-word window surrounding the placeholder in a similar way and all other words in the question text are ignored. In addition, they simply use a dot product to compute the “relevance” between the question and a contextual embedding. This simple model nevertheless works well, showing the extent to which this RC task can be done by very local context matching.

## 4 Experiments

### 4.1 Training Details

For training our conventional classifier, we use the implementation of *LambdaMART* (Wu et al., 2010) in the RankLib package.<sup>5</sup> We use this ranking algorithm since our problem is naturally a ranking problem and forests of boosted decision trees have been very successful lately (as seen, e.g., in many recent Kaggle competitions). We do not use all the features of *LambdaMART* since we are only scoring 1/0 loss on the first ranked proposal, rather than using an IR-style metric to score ranked results. We use Stanford’s neural network dependency parser (Chen and Manning, 2014) to parse all our document and question text, and all other features can be extracted without additional tools.

For training our neural networks, we only keep the most frequent  $|\mathcal{V}| = 50\text{k}$  words (including entity and placeholder markers), and map all other words to an *junk* <sub>$\ell$</sub>  token. We choose word embedding size  $d = 100$ , and use the 100-dimensional pre-trained *GloVe* word embeddings (Pennington et al., 2014) for initialization. The attention and output parameters are initialized from a uniform distribution between  $(-0.01, 0.01)$ , and the GRU

weights are initialized from a Gaussian distribution  $\mathcal{N}(0, 0.1)$ .

We use hidden size  $h = 128$  for *CNN* and 256 for *Daily Mail*. Optimization is carried out using vanilla stochastic gradient descent (SGD), with a fixed learning rate of 0.1. We sort all the examples by the length of its passage, and randomly sample a mini-batch of size 32 for each update. We also apply dropout with probability 0.2 to the embedding layer and gradient clipping when the norm of gradients exceeds 10.

Additionally, we think the original indices of entity markers are generated arbitrarily. We attempt to relabel the entity markers based on their first occurrence in the passage and question<sup>6</sup> and find that this step can make training converge faster as well bring slight gains. We report both results (with and without relabeling) for future reference.

All of our models are run on a single GPU (GeForce GTX TITAN X), with roughly a runtime of 3 hours per epoch for *CNN*, and 12 hours per epoch for *Daily Mail*. We run all the models up to 30 epochs and select the model that achieves the best accuracy on the development set.

We run our models 5 times independently with different random seeds and report average performance across the runs. We also report ensemble results which average the prediction probabilities of the 5 models.

### 4.2 Main Results

Table 2 presents our main results. The conventional feature-based classifier obtains 67.9% accuracy on the *CNN* test set. Not only does this significantly outperform any of the symbolic approaches reported in (Hermann et al., 2015), it also outperforms all the neural network systems from their paper and the best single-system result reported so far from (Hill et al., 2016). This suggests that the task might not be as difficult as suggested, and a simple feature set can cover many of the cases. Table 3 presents a feature ablation analysis of our entity-centric classifier on the development portion of the *CNN* dataset. It shows that  $n$ -gram match and frequency of entities are the two most important classes of features.

More dramatically, our single-model neural network surpasses the previous results by a large margin (over 5%). The relabeling process further im-

<sup>5</sup><https://sourceforge.net/p/lemur/wiki/RankLib/>.

<sup>6</sup>The first occurring entity is relabeled as @entity1, and the second one is relabeled as @entity2, and so on.

Model	CNN		Daily Mail	
	Dev	Test	Dev	Test
Frame-semantic model <sup>†</sup>	36.3	40.2	35.5	35.5
Word distance model <sup>†</sup>	50.5	50.9	56.4	55.5
Deep LSTM Reader <sup>†</sup>	55.0	57.0	63.3	62.2
Attentive Reader <sup>†</sup>	61.6	63.0	70.5	69.0
Impatient Reader <sup>†</sup>	61.8	63.8	69.0	68.0
MemNNs (window memory) <sup>‡</sup>	58.0	60.6	N/A	N/A
MemNNs (window memory + self-sup.) <sup>‡</sup>	63.4	66.8	N/A	N/A
MemNNs (ensemble) <sup>‡</sup>	66.2*	69.4*	N/A	N/A
Ours: Classifier	67.1	67.9	69.1	68.3
Ours: Neural net	72.5	72.7	76.9	76.0
Ours: Neural net (ensemble)	76.2*	76.5*	79.5*	78.7*
Ours: Neural net (relabeling)	<b>73.8</b>	<b>73.6</b>	<b>77.6</b>	<b>76.6</b>
Ours: Neural net (relabeling, ensemble)	<b>77.2*</b>	<b>77.6*</b>	<b>80.2*</b>	<b>79.2*</b>

Table 2: Accuracy of all models on the *CNN* and *Daily Mail* datasets. Results marked <sup>†</sup> are from (Hermann et al., 2015) and results marked <sup>‡</sup> are from (Hill et al., 2016). *Classifier* and *Neural net* denote our entity-centric classifier and neural network systems respectively. The numbers marked with \* indicate that the results are from ensemble models.

Features	Accuracy
Full model	67.1
– whether $e$ is in the passage	67.1
– whether $e$ is in the question	67.0
– frequency of $e$	<b>63.7</b>
– position of $e$	65.9
– $n$ -gram match	<b>60.5</b>
– word distance	65.4
– sentence co-occurrence	66.0
– dependency parse match	65.6

Table 3: Feature ablation analysis of our entity-centric classifier on the development portion of the *CNN* dataset. The numbers denote the accuracy after we exclude each feature from the full system, so a low number indicates an important feature.

proves the results by 0.6% and 0.9%, pushing up the state-of-the-art accuracies to 73.6% and 76.6% on the two datasets respectively. The ensembles of 5 models consistently bring further 2 – 4% gains.

Concurrently with our paper, Kadlec et al. (2016) and Kobayashi et al. (2016) also experiment on these two datasets and report competitive results. However, our model not only still outperforms theirs, but also appears to be structurally simpler. All these recent efforts converge to similar num-

bers, and we believe that they are approaching the ceiling performance of this task, as we will indicate in the next section.

## 5 Data Analysis

So far, we have good results via either of our systems. In this section, we aim to conduct an in-depth analysis and answer the following questions: (i) Since the dataset was created in an automatic and heuristic way, how many of the questions are trivial to answer, and how many are noisy and not answerable? (ii) What have these models learned? What are the prospects for further improving them? To study this, we randomly sampled 100 examples from the dev portion of the *CNN* dataset for analysis (see more details in Appendix A).

### 5.1 Breakdown of the Examples

After carefully analyzing these 100 examples, we roughly classify them into the following categories (if an example satisfies more than one category, we classify it into the earliest one):

**Exact match** The nearest words around the placeholder are also found in the passage surrounding an entity marker; the answer is self-evident.

**Sentence-level paraphrasing** The question text

Category	Question	Passage
Exact Match	<i>it 's clear @entity0 is leaning toward @placeholder</i> , says an expert who monitors @entity0	... @entity116 , who follows @entity0 's operations and propaganda closely , recently told @entity3 , <i>it 's clear @entity0 is leaning toward @entity60</i> in terms of doctrine , ideology and an emphasis on holding territory after operations . ...
Paraphrase	@placeholder says he understands why @entity0 wo n't play at his tournament	... @entity0 called me personally to let me know that he would n't be playing here at @entity23 , " @entity3 said on his @entity21 event 's website . ...
Partial clue	a tv movie based on @entity2 's book @placeholder casts a @entity76 actor as @entity5	... to @entity12 @entity2 professed that his @entity11 is not a religious book . ...
Multiple sent.	he 's doing a his - and - her duet all by himself , @entity6 said of @placeholder	... we got some groundbreaking performances , here too , tonight , @entity6 said . we got @entity17 , who will be doing some musical performances . he 's doing a his - and - her duet all by himself . ...
Coref. Error	rapper @placeholder " disgusted , " cancels upcoming show for @entity280	... with hip - hop star @entity246 saying on @entity247 that he was canceling an upcoming show for the @entity249 . ... (but @entity249 = @entity280 = SAEs)
Hard	pilot error and snow were reasons stated for @placeholder plane crash	... a small aircraft carrying @entity5 , @entity6 and @entity7 the @entity12 @entity3 crashed a few miles from @entity9 , near @entity10 , @entity11 . ...

Table 4: Some representative examples from each category.

is entailed/rephrased by *exactly* one sentence in the passage, so the answer can definitely be identified from that sentence.

**Partial clue** In many cases, even though we cannot find a complete semantic match between the question text and some sentence, we are still able to infer the answer through partial clues, such as some word/concept overlap.

**Multiple sentences** It requires processing multiple sentences to infer the correct answer.

**Coreference errors** It is unavoidable that there are many coreference errors in the dataset. This category includes those examples with critical coreference errors for the answer entity or key entities appearing in the question. Basically we treat this category as "not answerable".

**Ambiguous or very hard** This category includes examples for which we think humans are not able to obtain the correct answer (confidently).

No.	Category	(%)
1	Exact match	13
2	Paraphrasing	41
3	Partial clue	19
4	Multiple sentences	2
5	Coreference errors	8
6	Ambiguous / hard	17

Table 5: An estimate of the breakdown of the dataset into classes, based on the analysis of our sampled 100 examples from the *CNN* dataset.

Table 5 provides our estimate of the percentage for each category, and Table 4 presents one representative example from each category. To our surprise, "coreference errors" and "ambiguous/hard" cases account for 25% of this sample set, based on our manual analysis, and this certainly will be a barrier for training models with an accuracy much above 75% (although, of course, a model can sometimes make a lucky guess). Additionally, only 2 examples require multiple sentences for inference –



Category	Classifier	Neural net
Exact match	13 (100.0%)	13 (100.0%)
Paraphrasing	32 (78.1%)	39 (95.1%)
Partial clue	14 (73.7%)	17 (89.5%)
Multiple sentences	1 (50.0%)	1 (50.0%)
Coreference errors	4 (50.0%)	3 (37.5%)
Ambiguous / hard	2 (11.8%)	1 (5.9%)
All	66 (66.0%)	74 (74.0%)

Table 6: The per-category performance of our two systems.

this is a lower rate than we expected and Hermann et al. (2015) suggest. Therefore, we hypothesize that in most of the “answerable” cases, the goal is to identify the most relevant (single) sentence, and then to infer the answer based upon it.

## 5.2 Per-category Performance

Now, we further analyze the predictions of our two systems, based on the above categorization.

As seen in Table 6, we have the following observations: (i) The exact-match cases are quite simple and both systems get 100% correct. (ii) For the ambiguous/hard and entity-linking-error cases, meeting our expectations, both of the systems perform poorly. (iii) The two systems mainly differ in paraphrasing cases, and some of the “partial clue” cases. This clearly shows how neural networks are better capable of learning semantic matches involving paraphrasing or lexical variation between the two sentences. (iv) We believe that the neural-net system already achieves near-optimal performance on all the single-sentence and unambiguous cases. There does not seem to be much useful headroom for exploring more sophisticated natural language understanding approaches on this dataset.

## 6 Related Tasks

We briefly survey other tasks related to reading comprehension.

**MCTest** (Richardson et al., 2013) is an open-domain reading comprehension task, in the form of fictional short stories, accompanied by multiple-choice questions. It was carefully created using crowd sourcing, and aims at a 7-year-old reading comprehension level.

On the one hand, this dataset has a high demand on various reasoning capacities: over 50% of the questions require multiple sentences to answer

and also the questions come in assorted categories (*what, why, how, whose, which*, etc). On the other hand, the full dataset has only 660 paragraphs in total (each paragraph is associated with 4 questions), which renders training statistical models (especially complex ones) very difficult.

Up to now, the best solutions (Sachan et al., 2015; Wang et al., 2015) are still heavily relying on manually curated syntactic/semantic features, with the aid of additional knowledge (e.g., word embeddings, lexical/paragraph databases).

**Children Book Test** (Hill et al., 2016) was developed in a similar spirit to the *CNN/Daily Mail* datasets. It takes any consecutive 21 sentences from a children’s book – the first 20 sentences are used as the passage, and the goal is to infer a missing word in the 21st sentence (question and answer). The questions are also categorized by the type of the missing word: named entity, common noun, preposition or verb. According to the first study on this dataset (Hill et al., 2016), a language model (an  $n$ -gram model or a recurrent neural network) with local context is sufficient for predicting verbs or prepositions; however, for named entities or common nouns, it improves performance to scan through the whole paragraph to make predictions. So far, the best published results are reported by window-based memory networks.

**bAbI** (Weston et al., 2016) is a collection of artificial datasets, consisting of 20 different reasoning types. It encourages the development of models with the ability to chain reasoning, induction/deduction, etc., so that they can answer a question like “The football is in the *playground*” after reading a sequence of sentences “John is in the playground; Bob is in the office; John picked up the football; Bob went to the kitchen.” Various types of memory networks (Sukhbaatar et al., 2015; Kumar et al., 2016) have been shown effective on these tasks, and Lee et al. (2016) show that vector space models based on extensive problem analysis can obtain near-perfect accuracies on all the categories. Despite these promising results, this dataset is limited to a small vocabulary (only 100–200 words) and simple language variations, so there is still a huge gap from real-world datasets that we need to fill in.

## 7 Conclusion

In this paper, we carefully examined the recent *CNN/Daily Mail* reading comprehension task. Our

systems demonstrated state-of-the-art results, but more importantly, we performed a careful analysis of the dataset by hand.

Overall, we think the *CNN/Daily Mail* datasets are valuable datasets, which provide a promising avenue for training effective statistical models for reading comprehension tasks. Nevertheless, we argue that: (i) this dataset is still quite noisy due to its method of data creation and coreference errors; (ii) current neural networks have almost reached a performance ceiling on this dataset; and (iii) the required reasoning and inference level of this dataset is still quite simple.

As future work, we need to consider how we can utilize these datasets (and the models trained upon them) to help solve more complex RC reasoning tasks (with less annotated data).

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## A Samples and Labeled Categories from the CNN Dataset

For the analysis in Section 5, we uniformly sampled 100 examples from the development set of the CNN dataset. Table 8 provides a full index list of our samples and Table 7 presents our labeled categories.

Category	Sample IDs
Exact match (13)	8, 11, 23, 27, 28, 32, 43, 57, 63, 72, 86, 87, 99
Sentence-level paraphrasing (41)	0, 2, 7, 9, 12, 14, 16, 18, 19, 20, 29, 30, 31, 34, 36, 37, 39, 41, 42, 44, 47, 48, 52, 54, 58, 64, 65, 66, 69, 73, 74, 78, 80, 81, 82, 84, 85, 90, 92, 95, 96
Partial clues (19)	4, 17, 21, 24, 35, 38, 45, 53, 55, 56, 61, 62, 75, 83, 88, 89, 91, 97, 98
Multiple sentences (2)	5, 76
Coreference errors (8)	6, 22, 40, 46, 51, 60, 68, 94
Ambiguous or very hard (17)	1, 3, 10, 13, 15, 25, 26, 33, 49, 50, 59, 67, 70, 71, 77, 79, 93

Table 7: Our labeled categories of the 100 samples.

ID	Filename	ID	Filename
0	ddb1e746f88a22fee654ecde8f018e7586595045.question	1	2bef8ec21b10a3294b1496d9a86f29f0592d2300.question
2	38c702812a874f983e9890c32ba832841a327351.question	3	636857045cf266dd69b67b1e53617bed5253dc33.question
4	417cbffd5e6275b3c42cb88be222a9f6c7d415f1.question	5	ef96409c707a699e4055a1d0684eecd6b6e115c16.question
6	b4e157a6a34bf11a03e0b5cd55065c0f39ac8d60.question	7	1d75e7c59978c7c06f3aecaf52bc35b8919eee17.question
8	223c8e3aeddc3f65fee1964df17bb72f89b723e4.question	9	13d33b8c86375b0f5fde856116e91a7355c6fc5a.question
10	378fd418b8ec18dff406be07ec225e6bf53659f5.question	11	d8253b7f22662911c19ec4468f81b9db29df1746.question
12	80529c792d3a368861b404c1ce4d7ad3c12e552a.question	13	728e7b365e941d814676168c78c9c4f38892a550.question
14	3cf6fb2c0d09927a12add82b4a3f248da740d0de.question	15	04b827f84e60659258e19806afe9f8d10b764db1.question
16	f0abf359d71f7896abd09ff7b3319c70f2ded81e.question	17	b6696e0f2166a75fcefbe4f28d0ad06e420eef23.question
18	881ab3139c34e9d9f29eb11601321a234d096272.question	19	66f5208d62b543ee41accb7a560d63ff40413bac.question
20	f83a70d469fa667f0952959346b496fbf3cdb35c.question	21	1853813a80f83a1661dd3ff6695559674c749525e.question
22	02664d5e3af321afbaf4ee351ba1f24643746451.question	23	20417b5efb836530846ddf677d1bd0bbc831643c.question
24	42c25a01801228a863c508f9d9e95399ea5f37a4.question	25	70a3ba822770abcaf64dd131c85ec964d172c312.question
26	b6636e525ad58fde9a7c18187fb3412660d2cdd.question	27	6147c9f2b3d1cc6fbc57c2137f0356513f49bf46.question
28	262b855e2f24e1b2e4e0ba01ace81a1f214d729e.question	29	d7211f4d21f40461bb59954e53360eeb4bb6c664.question
30	be813e58ae9387a9fdaf771656c8e1122794e515.question	31	ad39c5217042f36e4c1458e9397b4a588bbf8cf9.question
32	9534c3907f1cd917d24a9e4f2afc5b38b82d9fca.question	33	3fbc4bf721a6e1aa60502089c46240d5c332c05.question
34	6efa2d6bad587bde65ca22d10eca83cf0176d84f.question	35	436aa25e28d3a026c4fcd658a852b6a24fc6935e.question
36	0c44d6ef109d33543cfd26c95c9c3f6fe33a995.question	37	8472b859c5a8d18454644d9acdb5edd1db175eb5.question
38	fb4dd20e0f464423b6407fd0d21cc4384905cf26.question	39	a192ddbcecf2b00260ae4c7c3c20df4d5ce47a85.question
40	f7133f844967483519dbf632e2f3fb90c5625a4c.question	41	29b274958eb057e8f1688f02ef8dbc1c6d06c954.question
42	8ea6ad57c1c5eb1950f50ea47231a5b3f32dd639.question	43	1e43f2349b17dac6d1b3143f8c5556e2257be92c.question
44	7f11f0b4f6bb9aaa3bdc74bfbaed5c869b26be97.question	45	8e6d8d984e51adb5071aad22680419854185eaea.question
46	57fc2b7ffcfbd1068fbc33b95d5786e2bff24698.question	47	57b773478955811a8077c98840d85af03e1b4f05.question
48	8d57700721b5835c3472ba73ef7abfad0c9c499f.question	49	f8eedded53c96e0cb98e2e95623714d2737f29da.question
50	4c488f41622ad48977a60c2283910f15a736417e.question	51	39680fd0bff53f2ca02f632eabb0c24d698f979e.question
52	add9cebe24c96b4a3c8e9a50cd2a57905b6defb.question	53	50317f7a626e23628e4bfd190e987ad5af7d283e.question
54	3f7ac912a75e4ef7a56987bff37440ffa14770c6.question	55	610012ef561027623f4b4e3b8310c1c41dc819cc.question
56	d9c2e9bfc71045be2ecd959676016599e4637ed1.question	57	848c068db210e0b255f83c4f8b01d24d21fb9c94.question
58	f5c2753703b66d26f43baf7f157803dc96eedbc.question	59	4f76379f1c7b1d4acc5a4c82ced64af6313698dd.question
60	e5bb1c27d07f1591929bf0283075ad1bc1fc0b50.question	61	33b911f9074c80eb18a57f657ad01393582059be.question
62	58c4c046654af52a3cb8f6890411a41c0dd0063b.question	63	7b03f730fda1b247e9f124b692e3298859785f3.question
64	ece6f4e047856d5a84811a67ac9780d48044e69a.question	65	35565dc6aacc0f1203842ef13aede0a14a8cf075.question
66	ddf3f2b06353fe8a9b50043f926eb3ab318e91b2.question	67	e248e59739c9c013a2b1b7385d881e0f879b341d.question
68	e86d3fa2a74625620bcae0003dfbe13416ee29cf.question	69	176bf03c9c19951a8ae5197505a568454a6d4526.question
70	ee694cb968ae99aea36f910355bf73da417274c0.question	71	7a666f78590edba7c4d73c4ea641c545295a513.question
72	91e3cdd46a70d6dfbe917c6241eab907da4b1562.question	73	e54d9bdc478ecc490608459d3405571979ef3f2.question
74	f3737e4de9864f083d6697293be650e02505768c.question	75	1fc7488755d24696a4ed1aabc0a21b8b9755d8c6.question
76	fb3eadd07b9f1df1f8a7a6b136ad6d06f4981442.question	77	1406bdad74b3f932342718d5d5d0946a906d73e2.question
78	54b639669b9db2e30715085745d4f98d058269ef.question	79	0a53102673f2bebc36ce74bf71db1b42a0187052.question
80	d5eb4f98551d23810bfef0e5b8a94037bcf58b0d.question	81	370de4ffe0f2f9691e4bd456ff344a6a337e0edf.question
82	12f32c770c86083ff21b25de7626505c06440018.question	83	9fb65cff3ce146e21e323a1462c3eff8fca3d4a0.question
84	1c2a14f525fa3802b8da52aebaa9abd2091f9215.question	85	f2416e14d89d40562284ba2d15f7d55c59c7e602.question
86	adcf5881856bcba1ad93d06a3c5431f6a0319ba.question	87	097d34b804c4c052591984d51444c4a97a3c41ac.question
88	773066c39bb3b593f676caf03f7e7370a8cd2a43.question	89	598cf5ff08ea75dcedda31ac1300e49cdf90893a.question
90	b66ebaaefb844f1216fd3d28eb160b08f42cde62.question	91	535a44842decde23c11bae50d9393b923897187e.question
92	e27ca3104a596171940db8501c4868ed2fbc8cea.question	93	bb07799b4193cfa90792f92a8c14d591754a7f3.question
94	83ff109c6ccd512abdf317220337b98ef551d94a.question	95	5ede07a1e4ac56a0155d852df0f5bb6bde3cb507.question
96	7a2a9a7fbb44b0e51512c61502ce2292170400c1.question	97	9dcdc052682b041cddf2fadc8e55f1bafce88fe61.question
98	0c2e28b7f373f29f3796d29047556766cc1dd709.question	99	2bdf1696bfd2579bb719402e9a6fa99cb8dbf587.question

Table 8: A full index list of our samples.